Oxygen abundance determinations in solar-type stars

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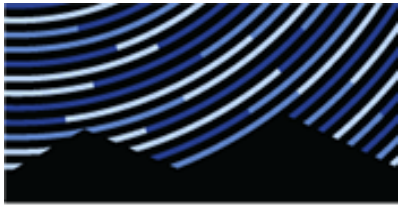


Mapping Oxygen in the Universe – Puerto de la Cruz, Tenerife / 14-18 May 2012

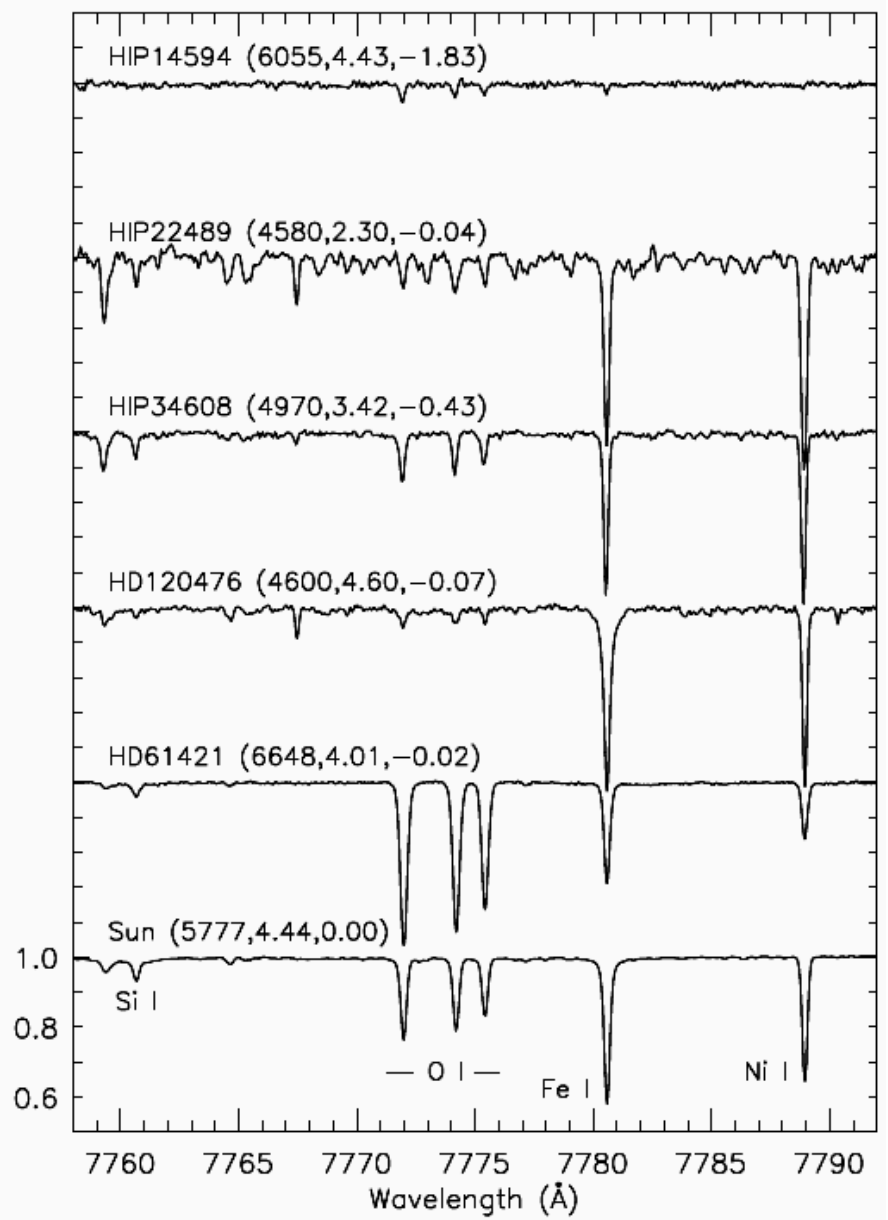
1. The Galactic disk.
   Thin/thick disk duality.

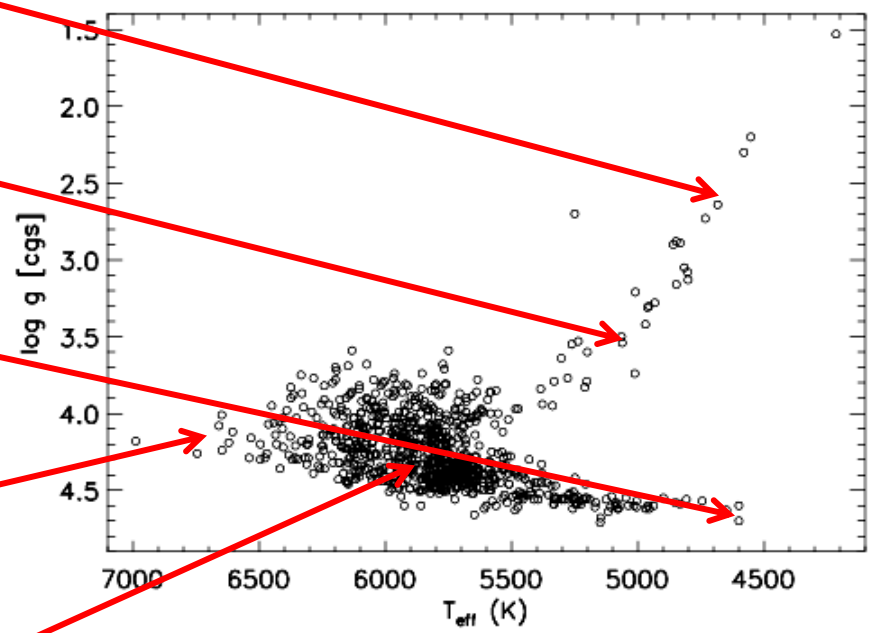
2. Low- and high-alpha halo stars.
   Field stars born in globular clusters.

3. Abundance anomalies in the Sun.
   Impact of planet formation.

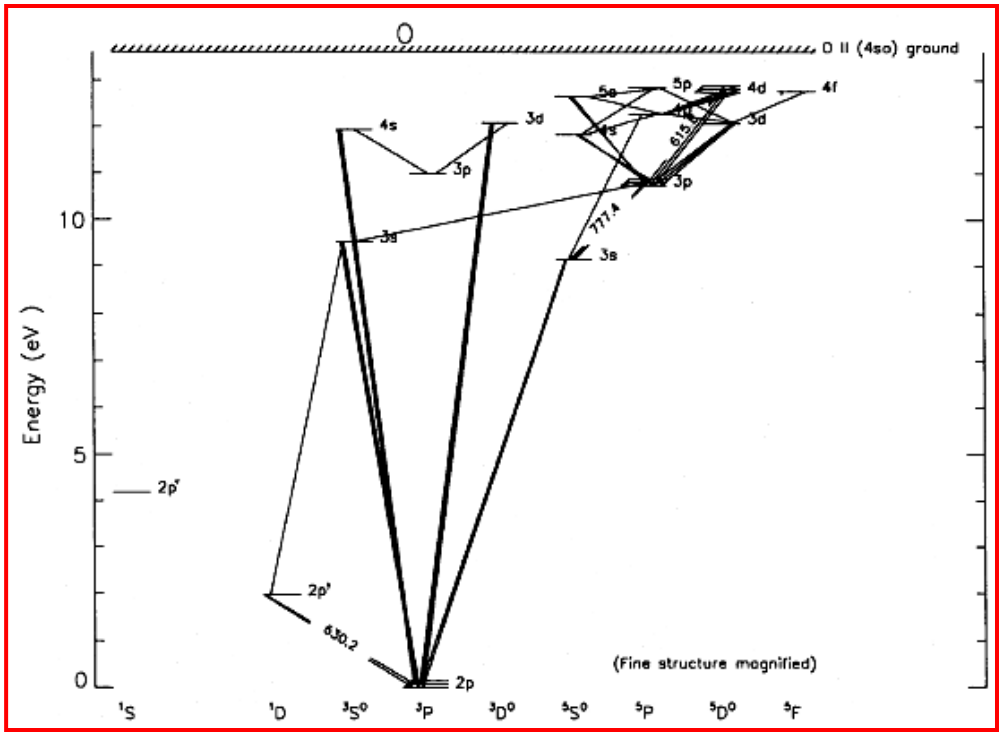
All based on oxygen abundances inferred from the 777 nm O I triplet in high-resolution (R~60,000), high S/N (>100) spectra of nearby (<200 pc) FGK stars.

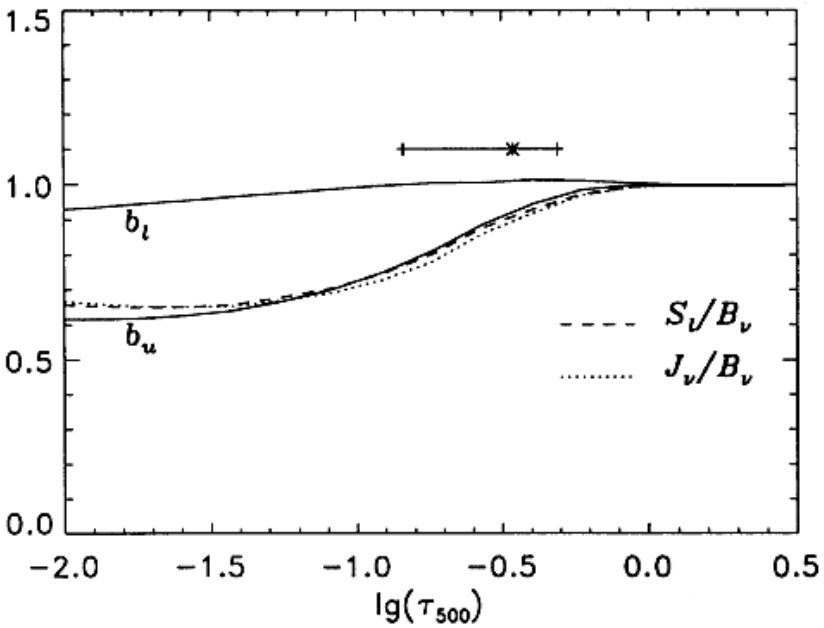
The 777 nm O I triplet in FGK stars





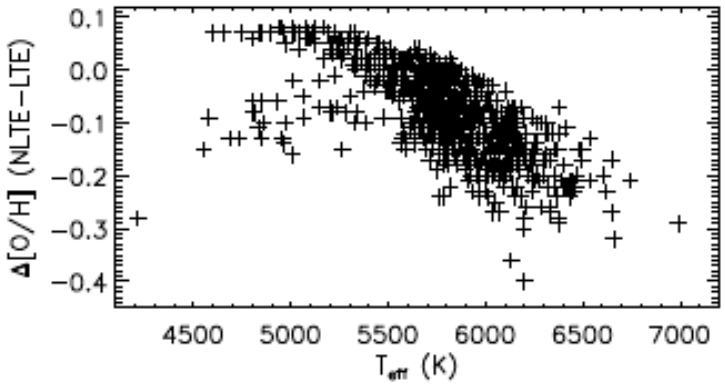
The 777 nm O I triplet : non-LTE line formation





Kiselman (1993)

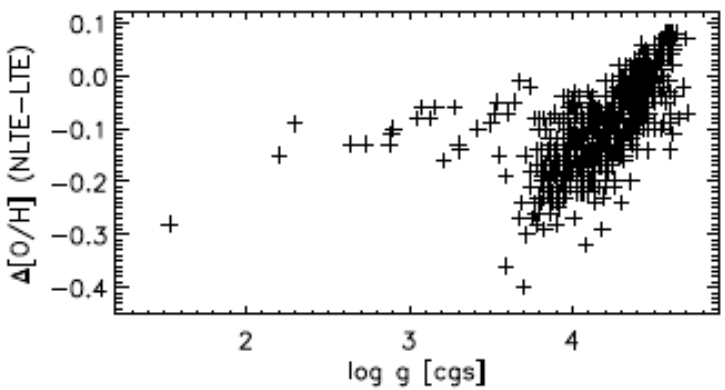
The 777 nm O I triplet : non-LTE abundance corrections



$$[O/H] = (\log N_O/N_H) - (\log N_O/N_H)_{Sun}$$

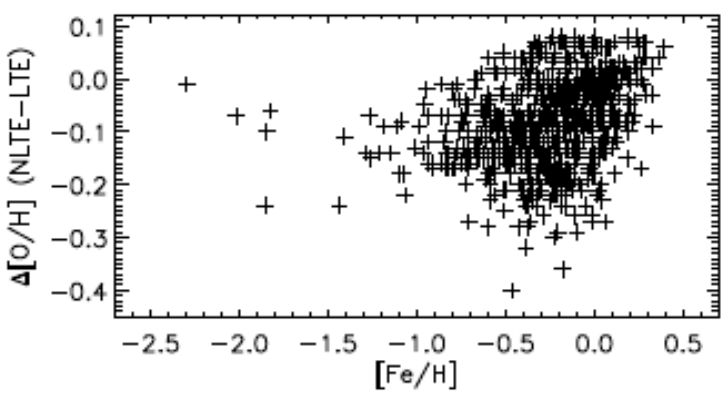
Ramírez, Allende Prieto, & Lambert (in preparation)

Non-LTE corrections by Ramírez et al. (2007)

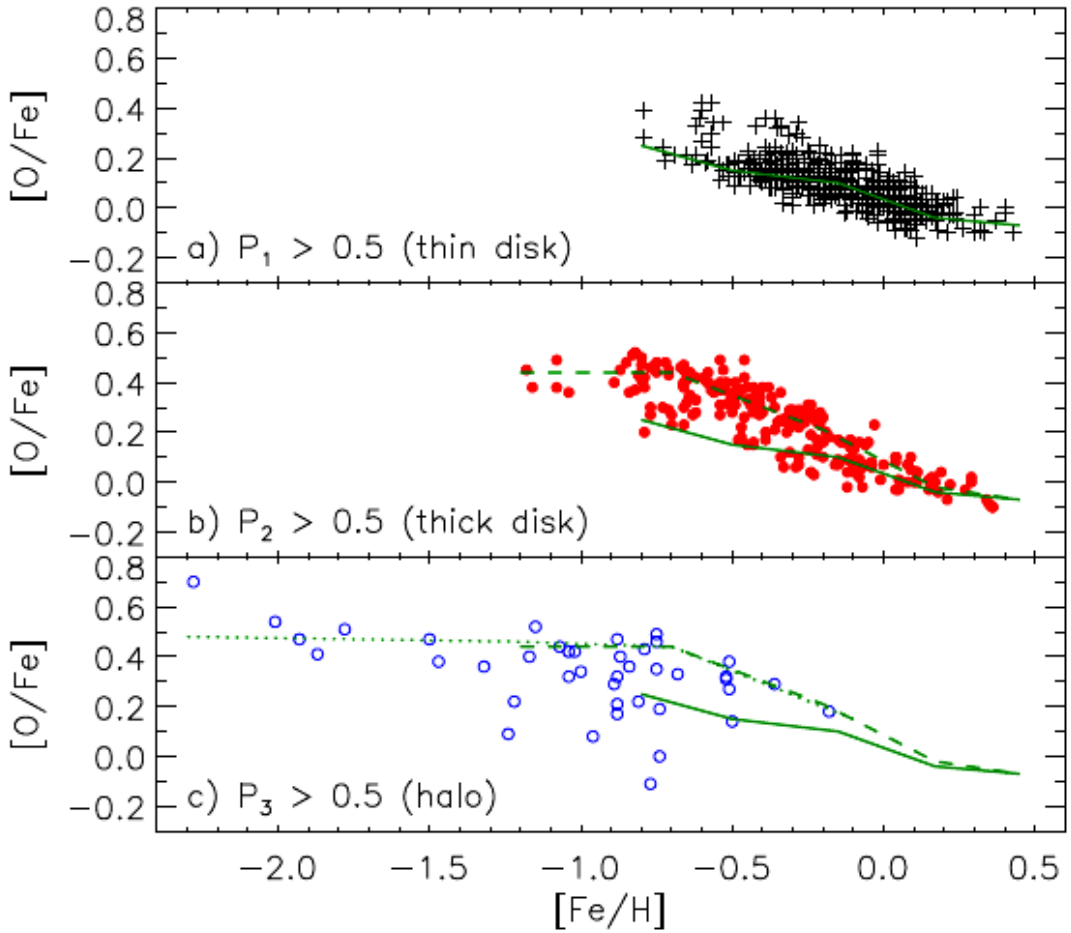


Model atom by Allende Prieto et al. (2002): 54 levels, 242 transitions
Kurucz (1993) “nover” models
Rate equations solved by TLUSTY (Hubeny 1988)
Spectrum synthesis with SYNSPEC (Hubeny & Lanz 1995)
No inelastic collisions with neutral H

See also: Takeda (1994), Kiselman (1993), Gratton et al. (1999), Fabbian et al. (2009)

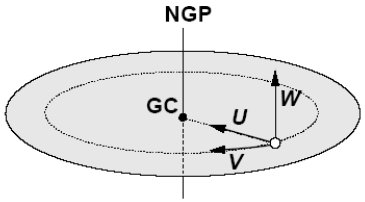


Oxygen in nearby FGK stars



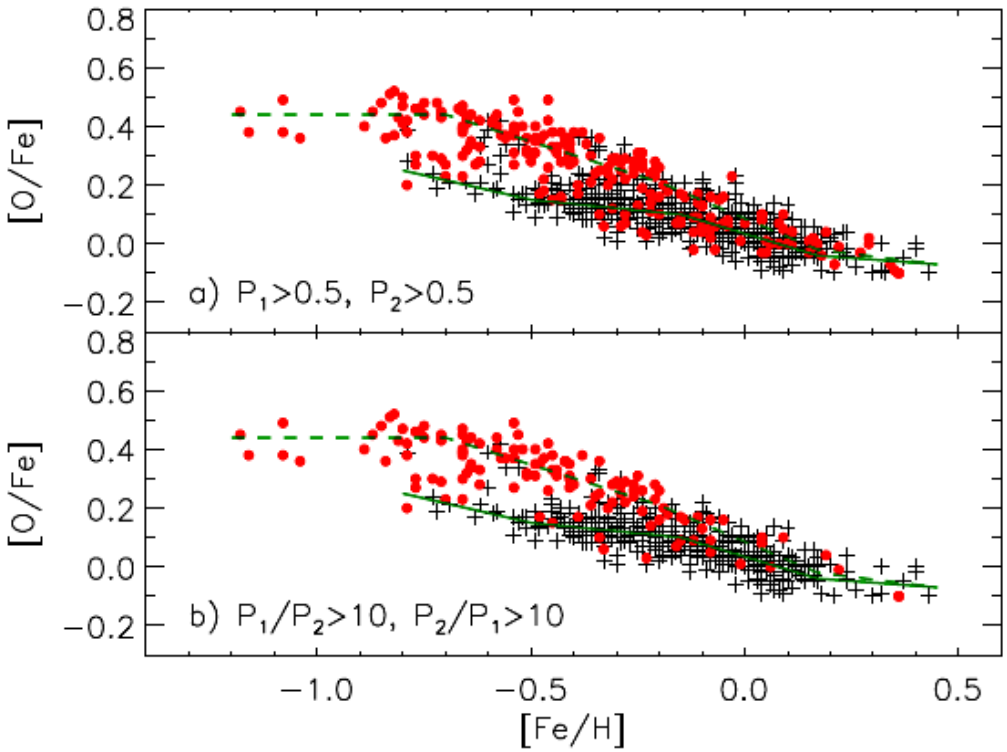
>800 stars
Δ[Fe/H]~0.05
Δ[O/Fe]~0.06

Ramírez, Allende Prieto, & Lambert (in preparation)



$$P_i = \frac{c_i}{(2\pi)^{3/2}\sigma_{U_i}\sigma_{V_i}\sigma_{W_i}} \exp\left\{-0.5\left[\frac{U^2}{\sigma^2_{U_i}} + \frac{(V-V_i)^2}{\sigma^2_{V_i}} + \frac{W^2}{\sigma^2_{W_i}}\right]\right\}$$

Disk: kinematics and abundances



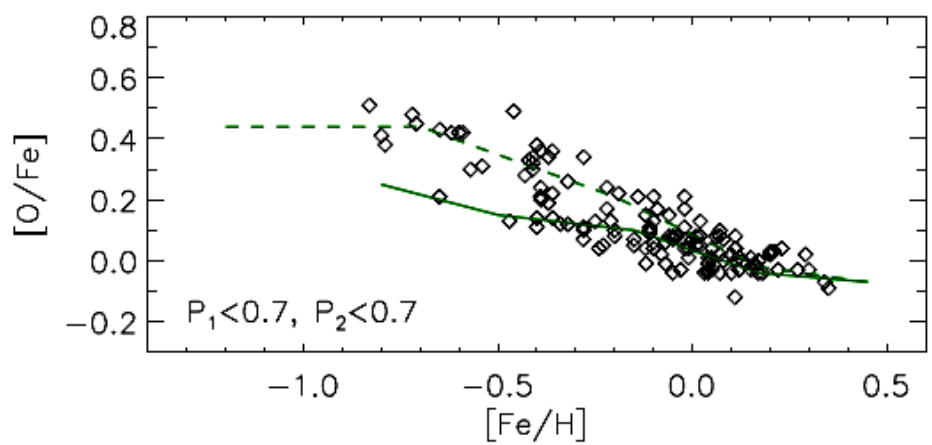
~10% thin-disk abundances but thick-disk kinematics

~20% thick-disk abundances but thin-disk kinematics

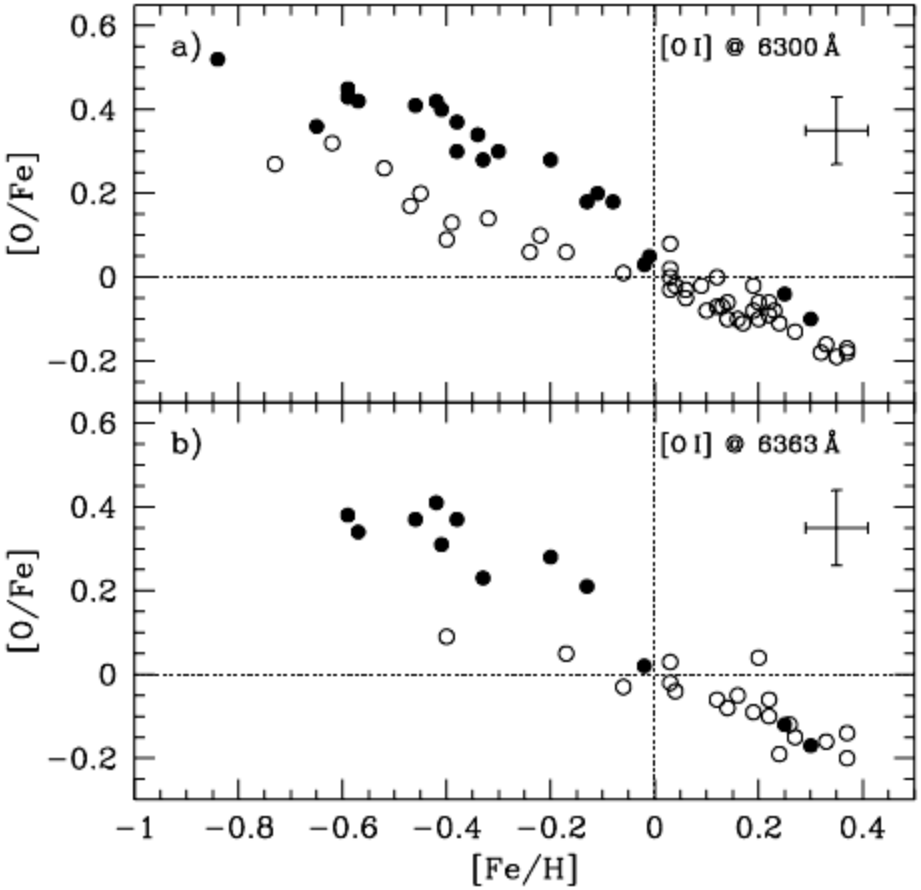
~8%, 14%

Observational errors can explain only ~2% of so-called “TKTA” stars

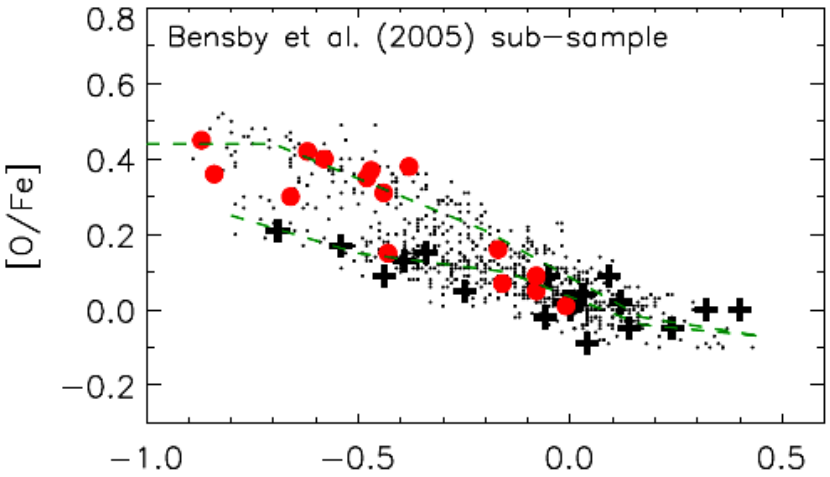
Stars with “intermediate” kinematics do not populate the intermediate [O/Fe] region; there is no such thing as a “transition” group.



Thin/thick disk duality?



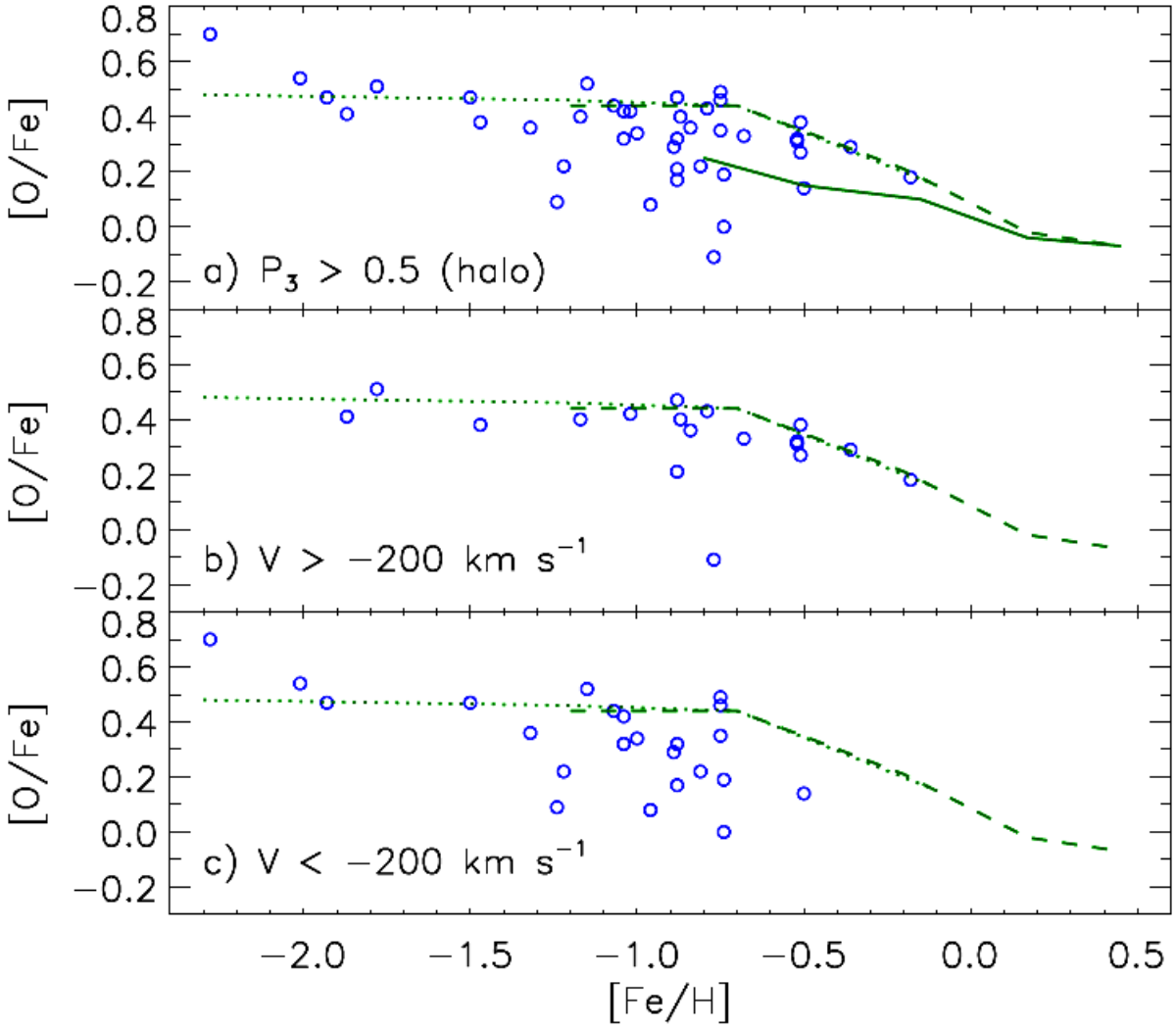
Bensby et al. (2004, 2005)



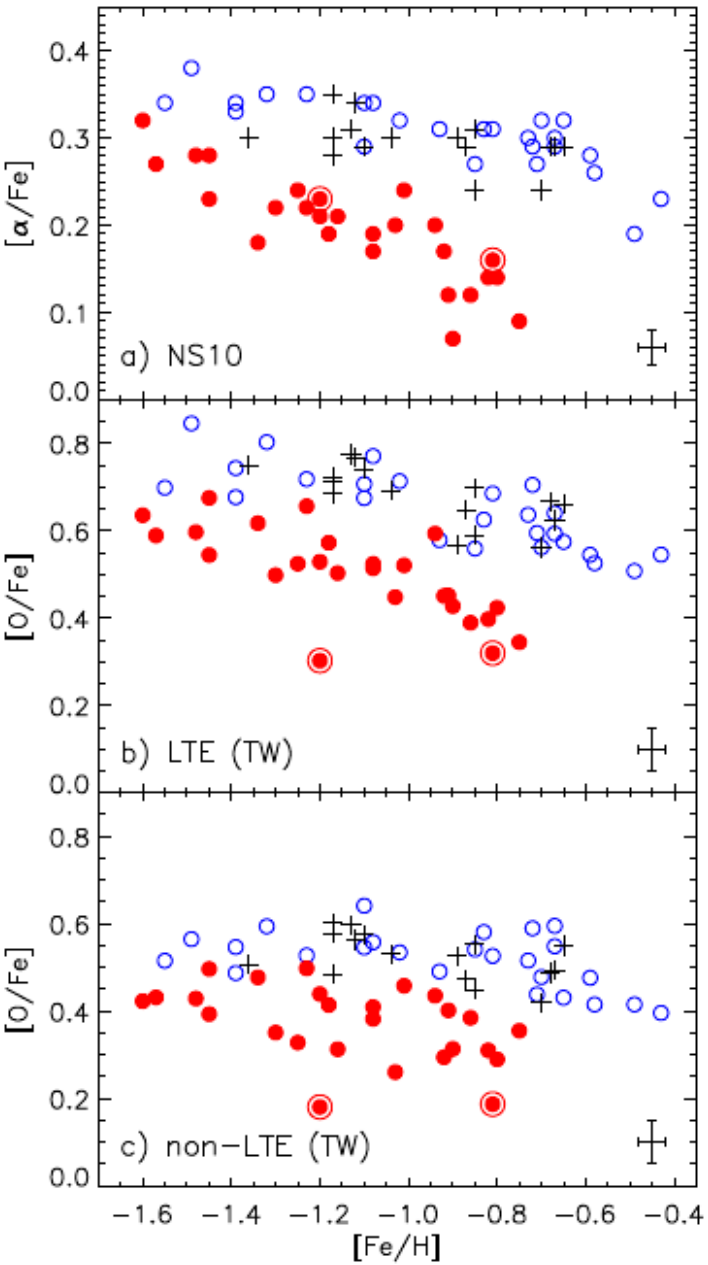
The kinematic thin/thick disk separation does not result in a perfect separation in chemical abundances, unless the sample is heavily biased in kinematics and has few stars.

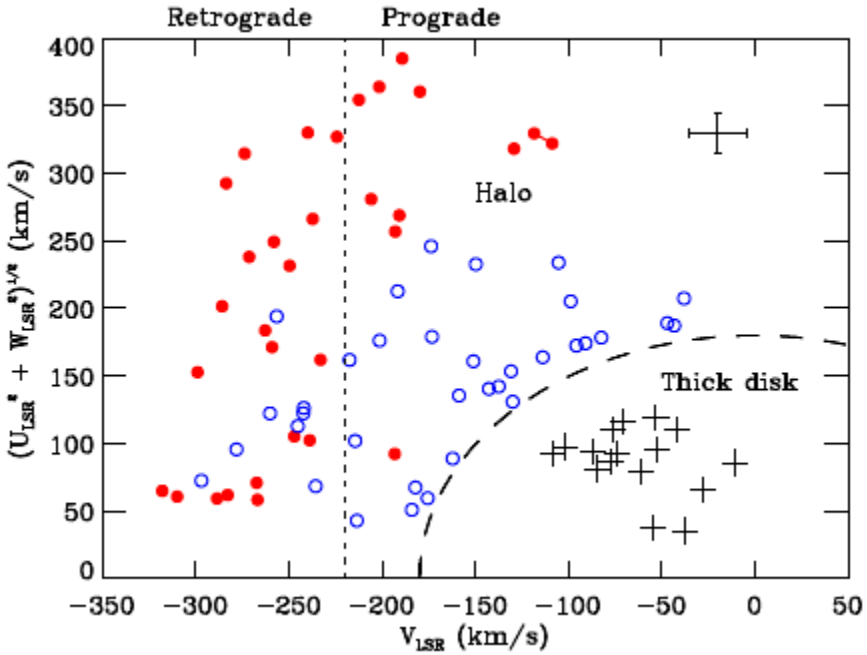
→ Important implications for Milky Way's disk formation models.

Halo stars (dwarfs and subgiants)



Two distinct halo populations in the solar neighborhood

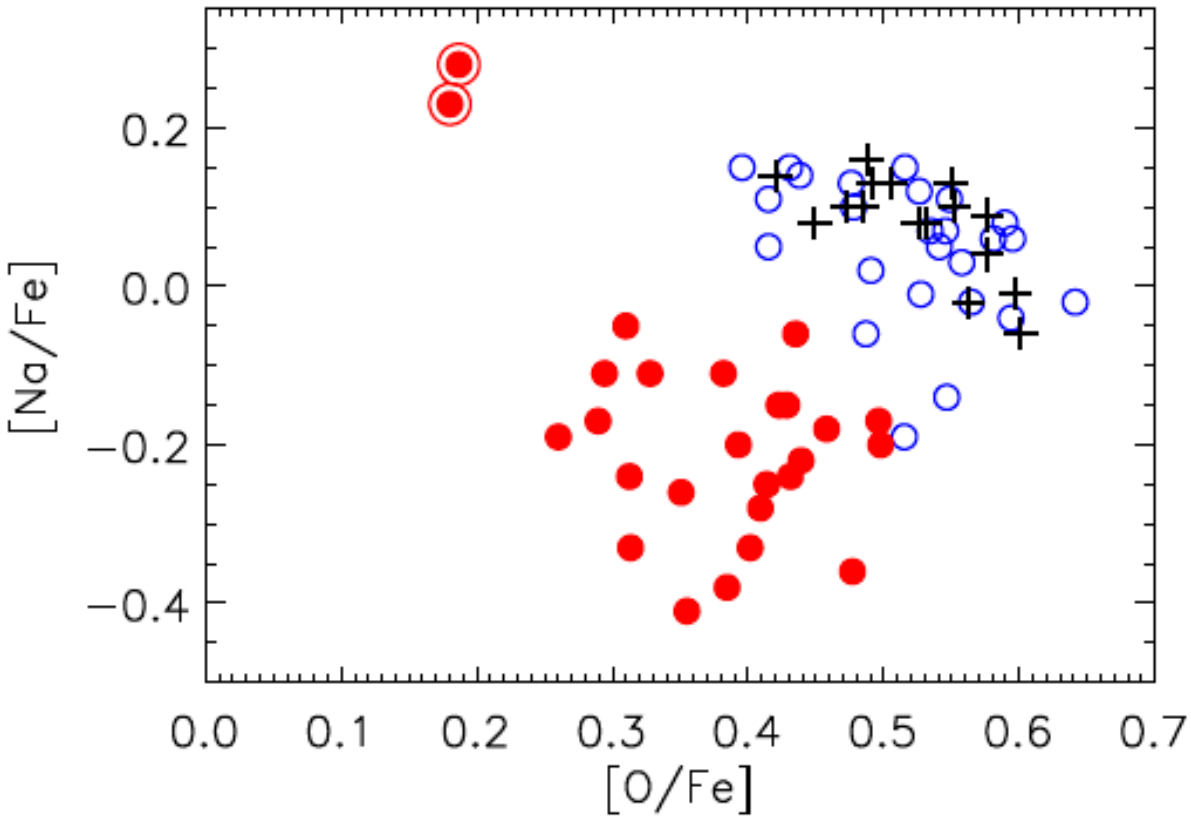




Nissen & Schuster (2010, 2011)
Schuster et al. (2012)

Ramírez, Meléndez, & Chanamé (in preparation)

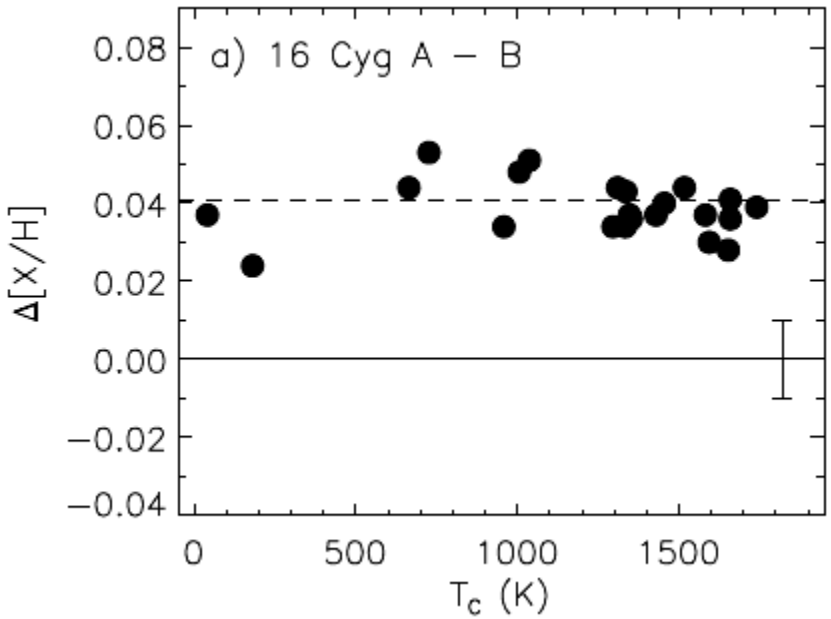
Field halo stars born in globular clusters?



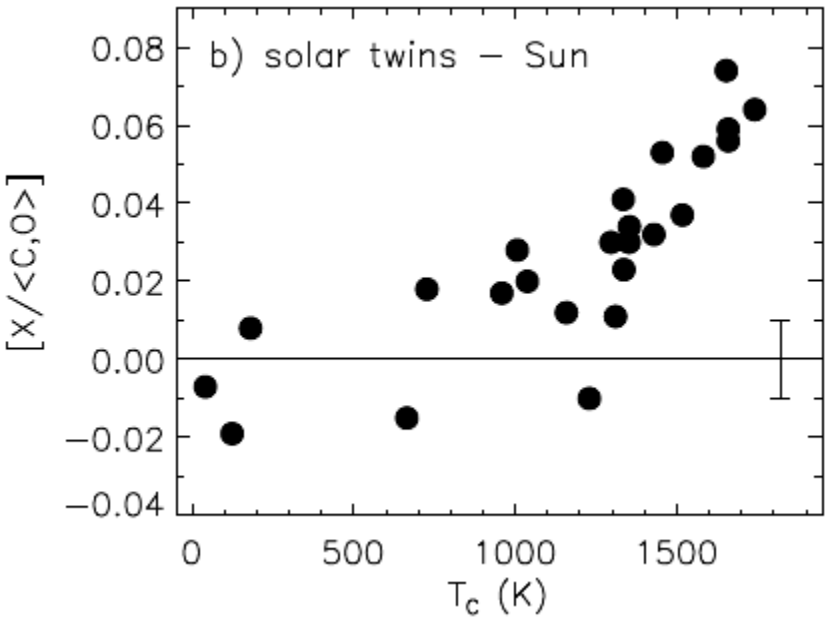
G53-41 and G150-40 show the signatures of abundance anomalies seen in GC stars
2/67 stars → >3% of metal-poor local field stars were born in GCs

Ramírez, Meléndez, & Chanamé (in preparation)

High-precision abundance analysis of solar twin stars



16 Cyg B: gas giant planet host

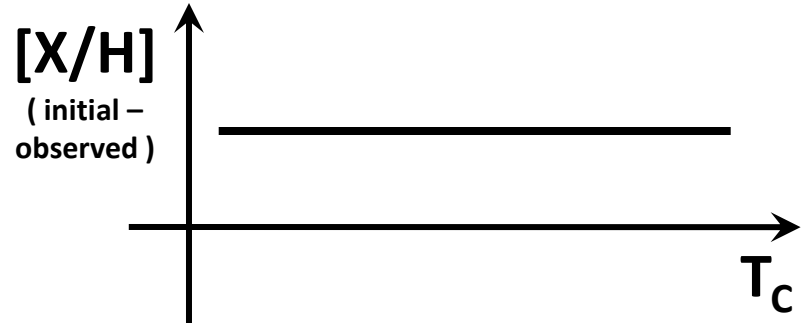


Sun: rocky + gas giant planet host

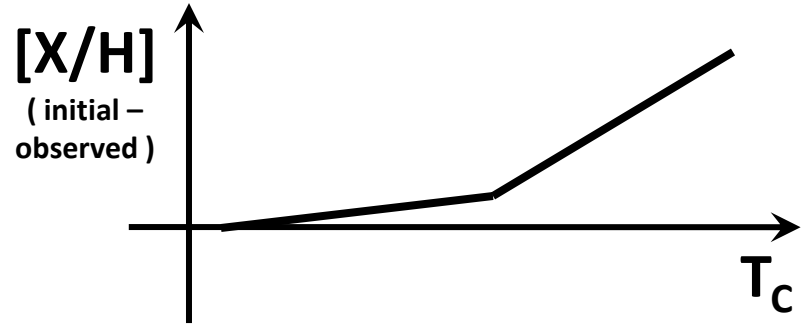
Meléndez et al. (2009, 2012), Ramírez et al. (2009, 2010, 2011)
Schuler et al. (2010), Gonzalez (2010)

But see also: González-Hernández et al. (2010, 2011), Schuler et al. (2011)

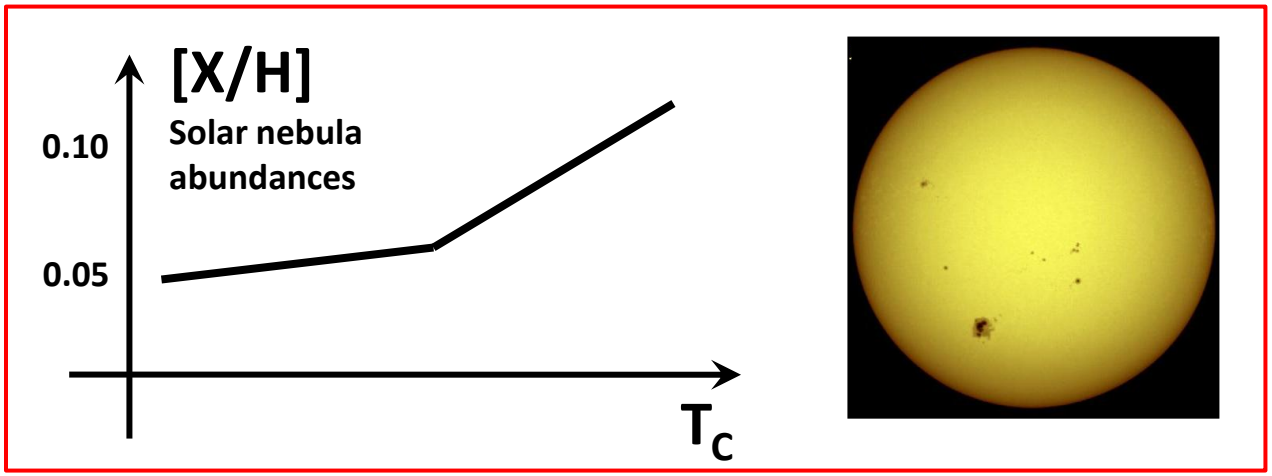
A little help to solve the solar oxygen abundance crisis?



$M_{CZ} \sim 0.10 M_*$
($\tau \sim 5$Myr)



$M_{CZ} \sim 0.02 M_*$
($\tau > 10$Myr)



Conclusions

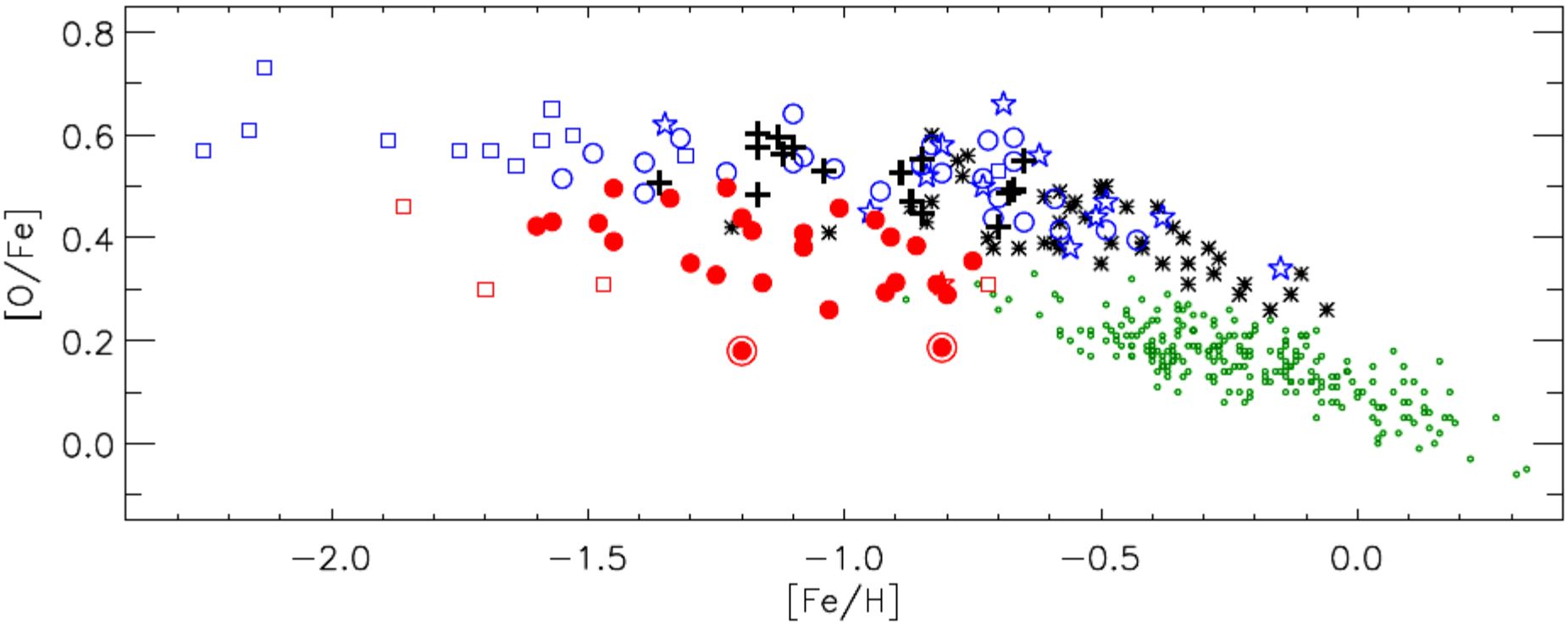
- The 777 nm O I triplet lines are excellent indicators of oxygen abundance in FGK-type stars ("solar-type"), provided they are accurately corrected for non-LTE effects.

- The traditional approach of separating thin-disk and thick-disk stars using kinematics does not result in a perfect separation in chemical abundances. Stars with "intermediate" abundances exist in large numbers, but they do not have intermediate kinematics.

- The local halo can be divided into low-alpha and high-alpha components. Oxygen behaves like an alpha element, except for 2 stars (G53-41 and G150-40) which have very low O and highly enhanced Na. These two stars are firm candidates for field halo stars born in globular clusters. If true, >3% of field halo stars were born in GCs.

- Planet formation may imprint chemical signatures in the photospheres of stars. If that is the case, the formation of the solar system's gas giants decreased the oxygen abundance in the solar convective envelope.

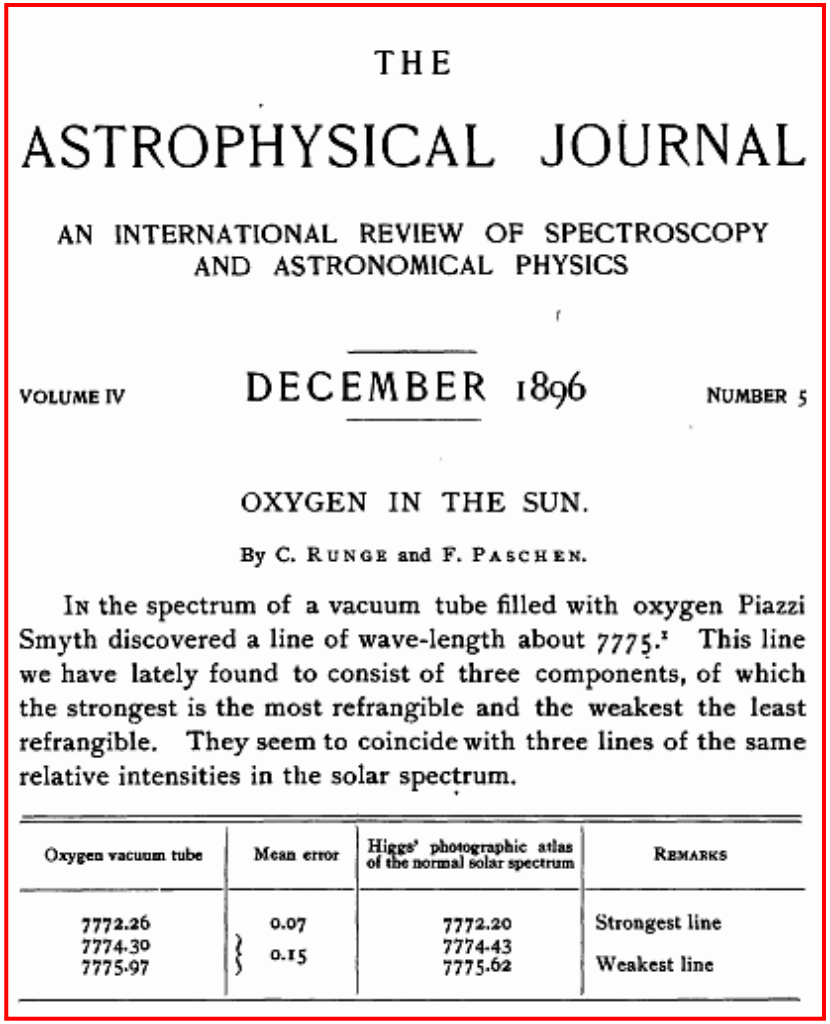
Oxygen abundances in nearby FGK dwarfs: Local stellar populations



Data from:

Ramírez, Allende Prieto, & Lambert (2007, in prep.)	***Disk***
Nissen & Schuster (2010), Ramírez, Chanamé, & Meléndez (in prep.)	***Metal-rich halo***
Meléndez et al. (2006)	***Metal-poor halo***

The 777 nm O I triplet



THE

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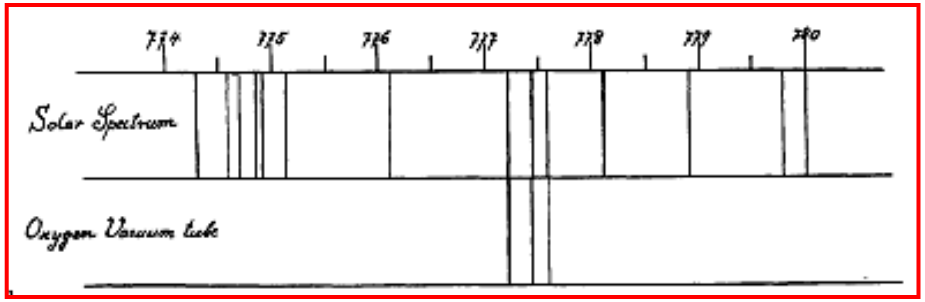
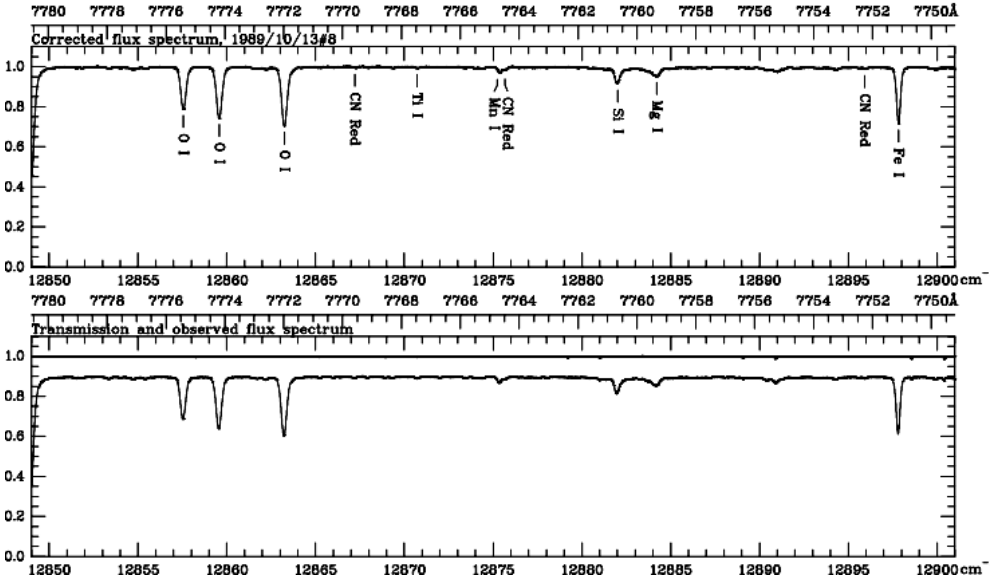
OXYGEN IN THE SUN.

By C. Runge and F. Paschen.

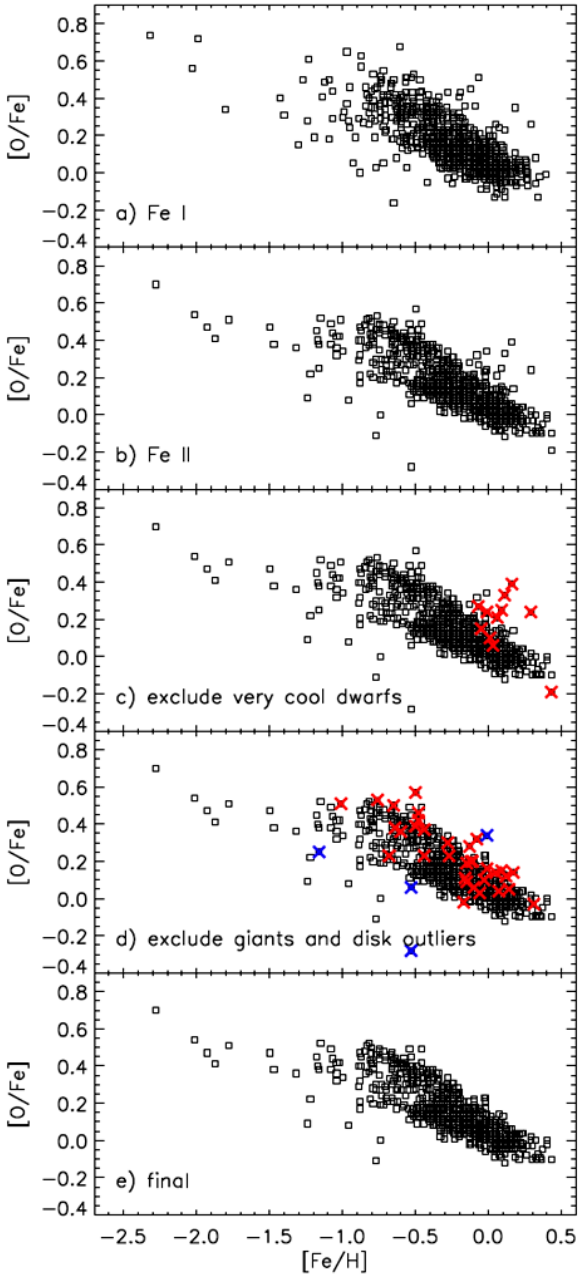
In the spectrum of a vacuum tube filled with oxygen Piazzi Smyth discovered a line of wave-length about 7775.[1] This line we have lately found to consist of three components, of which the strongest is the most refrangible and the weakest the least refrangible. They seem to coincide with three lines of the same relative intensities in the solar spectrum.

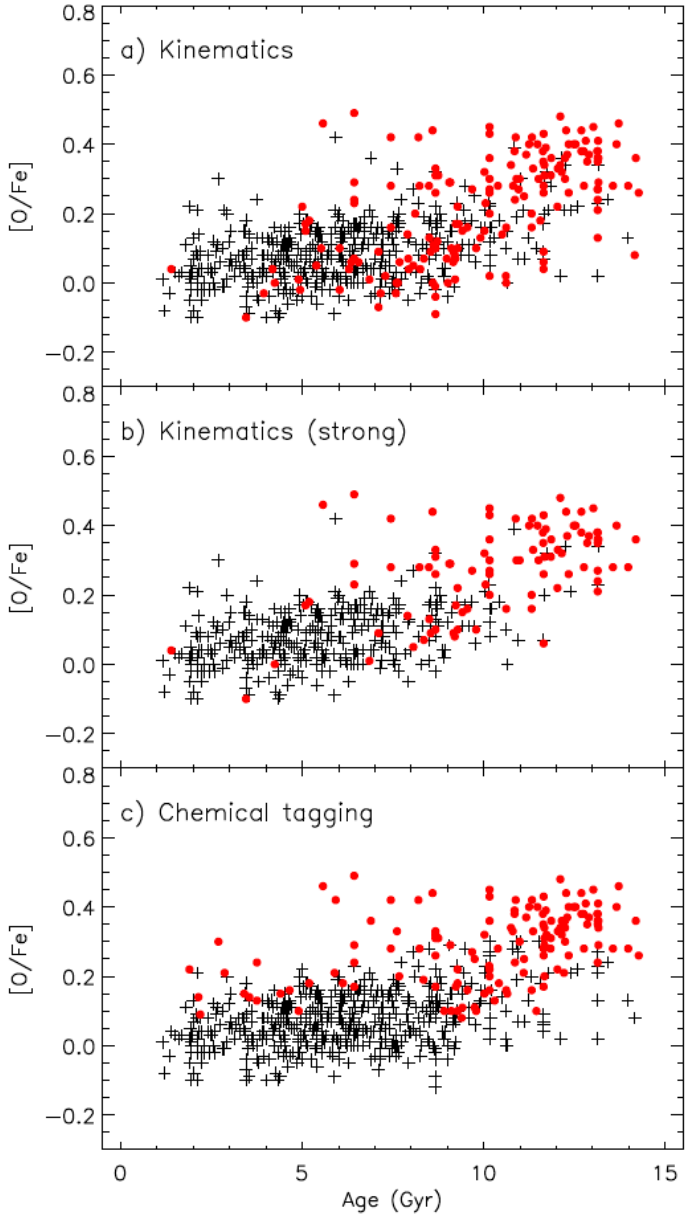
Oxygen vacuum tube	Mean error	Higgs' photographic atlas of the normal solar spectrum	Remarks
7772.26	0.07	7772.20	Strongest line
7774.30	0.15	7774.43	
7775.97		7775.62	Weakest line

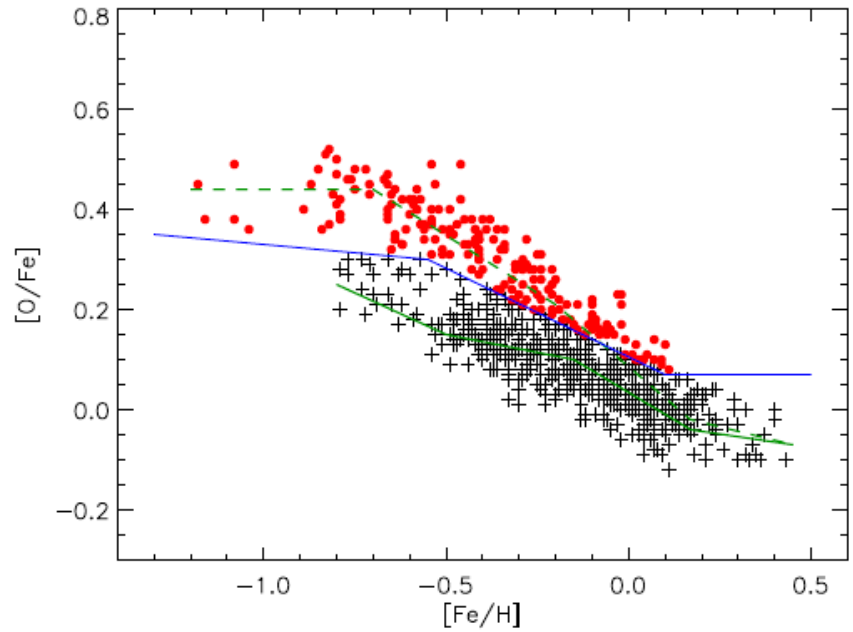


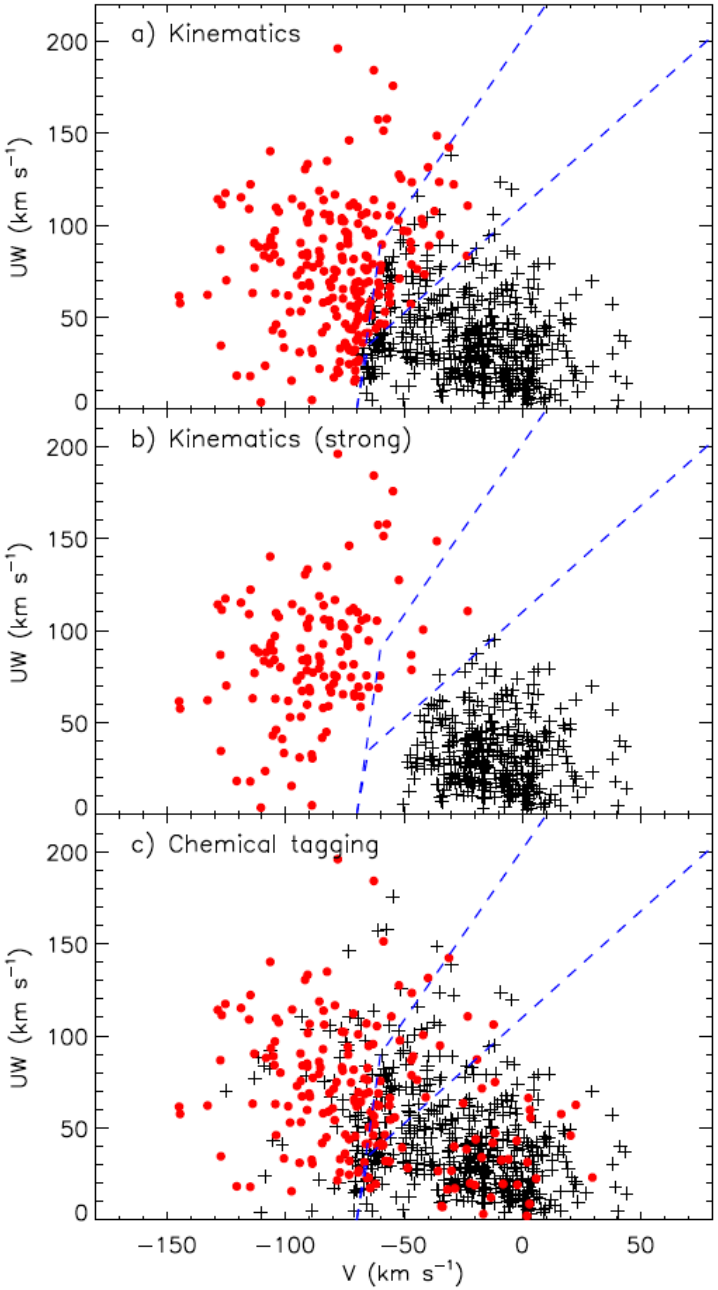


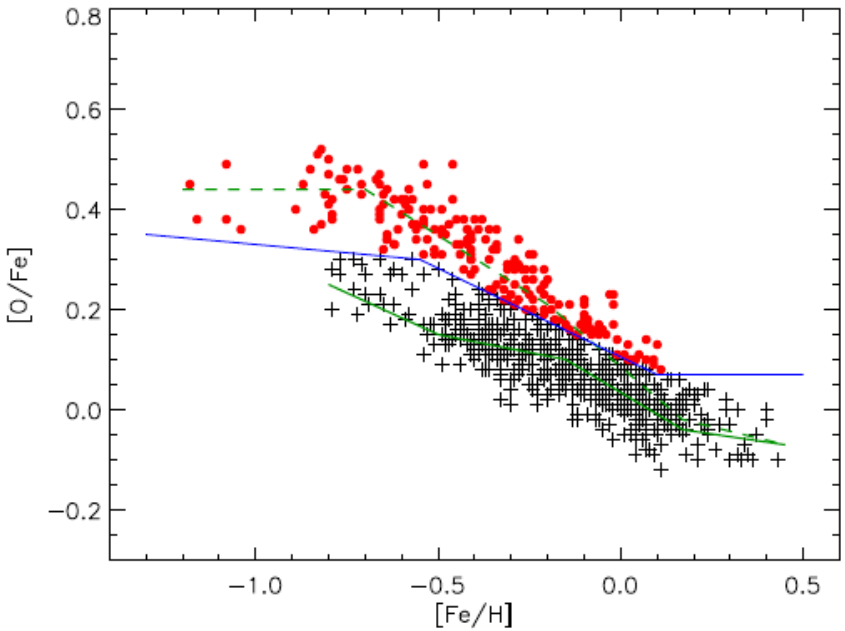
Wallace & Hinkle (2011)

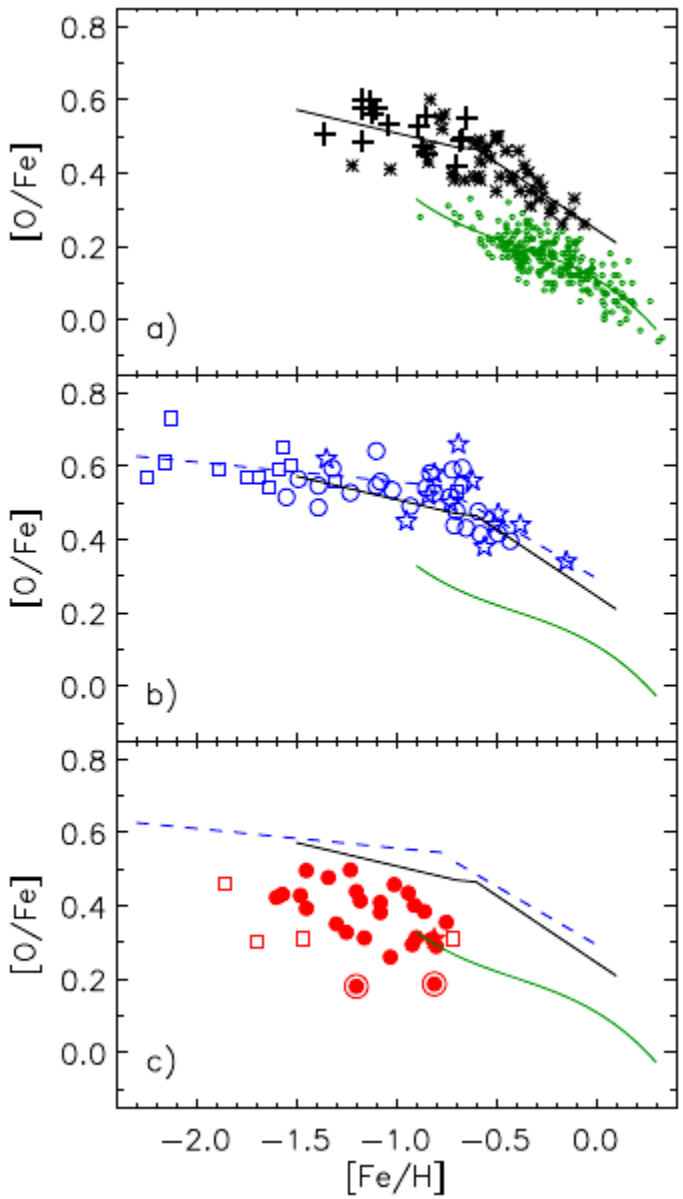

a) Fe I
b) Fe II
c) exclude very cool dwarfs
d) exclude giants and disk outliers
e) final
[O/Fe]
[Fe/H]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5

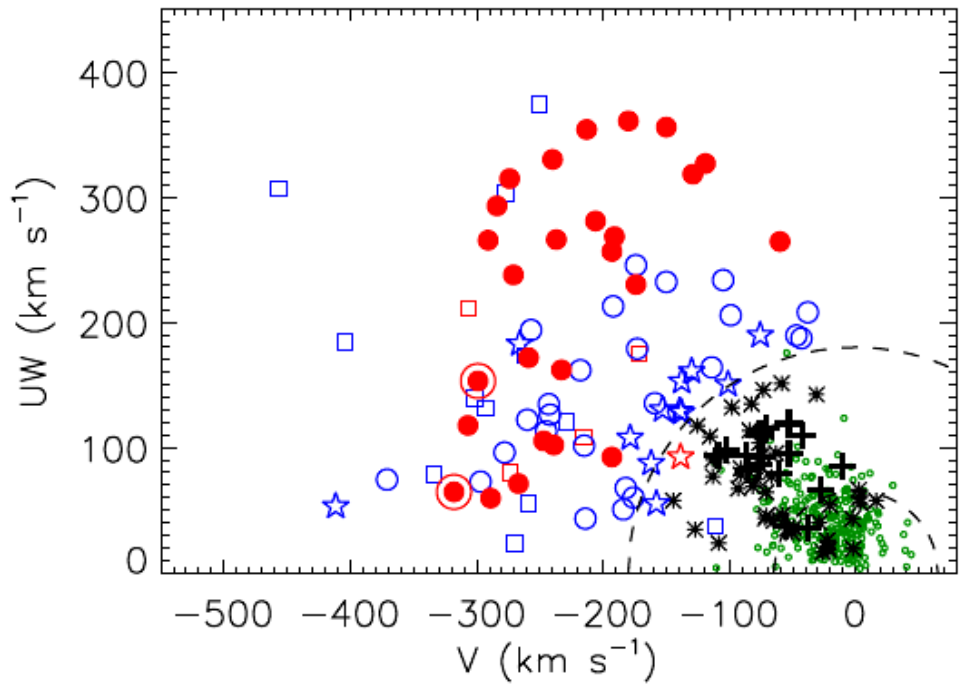

a) Kinematics
b) Kinematics (strong)
c) Chemical tagging
[O/Fe]
Age (Gyr)
0.8
0.6
0.4
0.2
0.0
−0.2
0
5
10
15

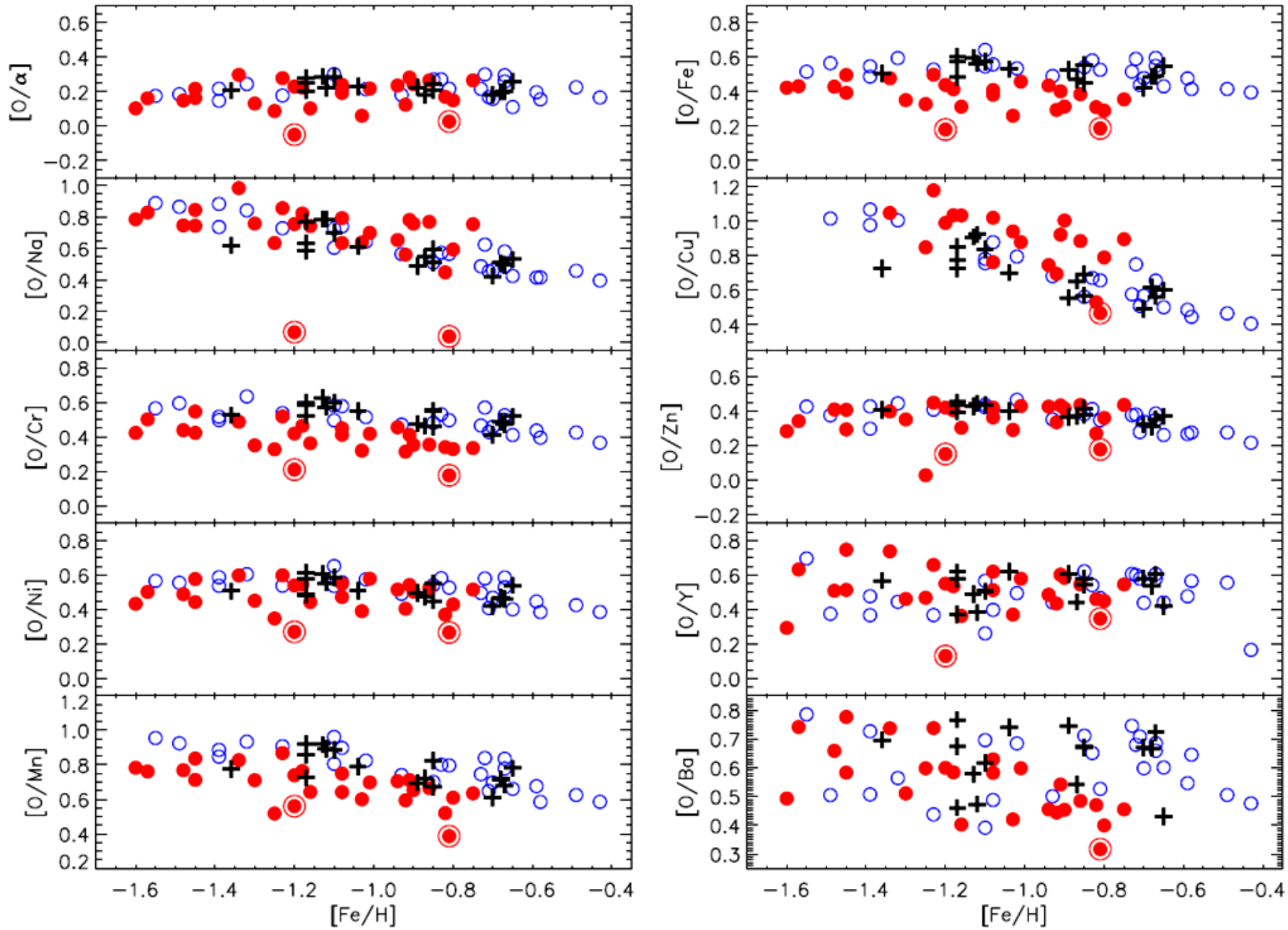

[O/Fe]
[Fe/H]
0.8
0.6
0.4
0.2
0.0
−0.2
−1.0
−0.5
0.0
0.5


a) Kinematics
b) Kinematics (strong)
c) Chemical tagging
UW (km s^{-1})
V (km s^{-1})
200
150
100
50
0
−150
−100
−50
0
50


[O/Fe]
[Fe/H]
0.8
0.6
0.4
0.2
0.0
−0.2
−1.0
−0.5
0.0
0.5


[O/Fe]
[Fe/H]
a)
b)
c)
0.0
0.2
0.4
0.6
0.8
−2.0
−1.5
−1.0
−0.5
0.0


UW (km s^{-1})
V (km s^{-1})
0
100
200
300
400
−500
−400
−300
−200
−100
0


[O/α]
[O/Na]
[O/Cr]
[O/Ni]
[O/Mn]
[O/Fe]
[O/Cu]
[O/Zn]
[O/Y]
[O/Ba]
[Fe/H]
[Fe/H]